Stockwell Coherence of the Motor Resting State Reduces Within-Subject Variability Caused by Inadvertent Body Movements

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INTRODUCTION

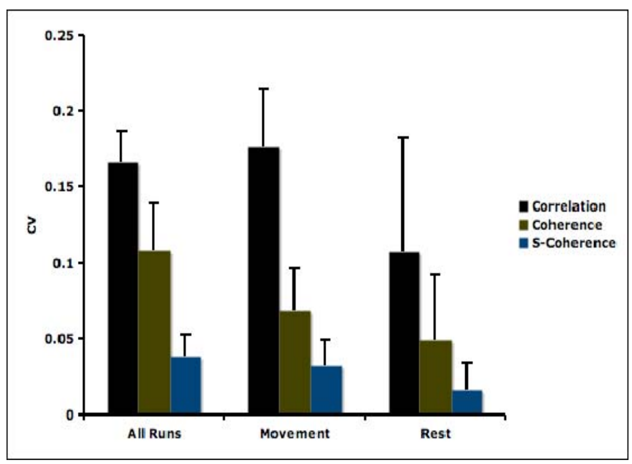
Resting-state functional MRI analysis techniques that determine the similarity between time varying signals of seed and target regions (e.g., by cross-correlation in the time domain [1,2] and coherence in the frequency domain [3,4]) assume the signals are stationary. However, the resting-state is neither a static phenomenon nor is reproducible [5]; it varies greatly within and between subjects, and can be disrupted by inadvertent body movements and cognitive processes. In this study, we introduce an analysis approach based on the Stockwell transform [6] to temporally resolve coherence between resting-state signals. We demonstrate how Stockwell coherence (S-Coherence) can be used to reduce the contribution of unwanted hand movements in the determination of the resting-state connectivity within the motor network of the human brain. We hypothesize that S-Coherence exhibits lesser within-subject variability in comparison with existing techniques (temporal cross-correlation and coherence) that assume stationary signals.

METHODS

Four healthy, right-handed volunteers participated in the study, which was approved by the research ethics board governing the institution. For each subject, four series of resting-state T_2*-weighted images were collected to encompass the motor cortex (GRE-EPI: TR = 2000 ms, TE = 30 ms, 24-cm FOV; fifteen 5-mm thick slices, 64x64 matrix size). The first two series were collected while the subject was at rest with eyes open. During the other two series, subjects were asked to perform 2-second visually cued bilateral (series 3) or unilateral (series 4) finger flexions at three different times. An additional series was collected during the performance of a bilateral finger movement task (five visually-cued blocks of 20 seconds of self-paced finger movements alternating with 20 seconds of rest) to be used as a motor cortex localizer, in order to select 300 voxels within the left (seed) and right (target) hemispheres. After low-pass filtering (0.1 Hz cut off frequency), temporal cross-correlation was performed between the average signal from the seed region and each of the voxels within the target region. The average Pearson's correlation coefficient of these 300 correlations was taken as the value of resting-state connectivity. For coherence, connectivity was taken as the average of the coherences calculated between the average signal of the seed region and each of the voxels of the target region, up to a frequency of 0.1 Hz. To compute S-Coherence for each voxel in the target region, the Stockwell transforms (i.e., temporally resolved frequency spectra) for both the average seed signal and the target voxel time course are first computed. Similar to the computation of coherence [3], the Stockwell auto-spectra for the seed region and target voxel as well as their cross-spectrum are calculated, and the ratio of the square of the cross-spectrum to the product of the auto-spectra is defined as S-Coherence. The result is a time-frequency spectrum of coherence. The mean S-Coherence across time and for frequencies up to 0.1Hz was recorded as S-Coherence connectivity for that voxel. The average for all voxels was taken as the final measurement of connectivity. To compute and compare within-subject coefficients of variation (CVs) for each of cross-correlation, coherence, and S-Coherence, all values underwent a Fisher transformation. For each subject, the within-subject CV was computed for (a) all four resting-state series, (b) the two runs with hand movements, and (c) for the two runs with no movement.

RESULTS

For all four subjects, S-Coherence successfully resolved the presence of hand movements within the seed and target regions in time and frequency. The within-subject CVs for each of cross-correlation, coherence, and S-Coherence are shown in the figure. An ANOVA demonstrated that when considering the two series with no movement, there was no significant difference between connectivity analysis methods. When considering the two runs with movement, the within-subject CV of cross-correlation was significantly greater than both coherence ($p = 0.025$) and S-Coherence ($p = 0.013$). For all four series, the within-subject CV of S-Coherence was significantly less than both cross-correlation ($p = 0.005$) and coherence ($p = 0.015$).



CONCLUSIONS

Our results show that S-Coherence possesses significantly less within-subject variability in the presence of inadvertent movements during a resting-state session. The fact that the within-subject CV for the two runs with no movement did not differ between cross-correlation, coherence, and S-Coherence, suggests that this significantly reduced within-subject CV for S-Coherence is indeed the result of the ability of S-Coherence to overcome signal variation associated with hand movements.

The human brain is never fully at rest. Consequently, brain activity that negatively impacts the estimation of the resting-state is inevitable. Approaches like S-Coherence that resolve the similarity between time varying signals from spatially distinct brain regions in both time and frequency domains have the potential to reduce the effect of unwanted signals during resting-state analysis.

References

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